UWB RADAR HOLOGRAPHY APPLIED TO RCS SIGNATURE REDUCTION OF MILITARY VEHICLES

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INTRODUCTION

Ultra wide band (UWB) radar holography is a unique technique developed at PNNL for the U. S. Army to obtain nearfield "3-D" images and scattering characteristics of full-size vehicles in the field and at production line facilities. The extremely high-resolution imaging capability of this technique maps a vehicle's scattering areas and identifies the "hot spots" which dominate the far-field signature to the enemy's radar receiver. The combination of generating near-field high resolution images and RCS measurements with the same data provides a very efficient LO signature reduction tool for the Army, Air Force and Navy.

Figure 1 is an end view of the “3-D” RCS scanner imaging the F-117 at a U. S. Air Force base. The scanner was towed to the base with a four wheel drive pickup and set up to perform tests on the tarmac.

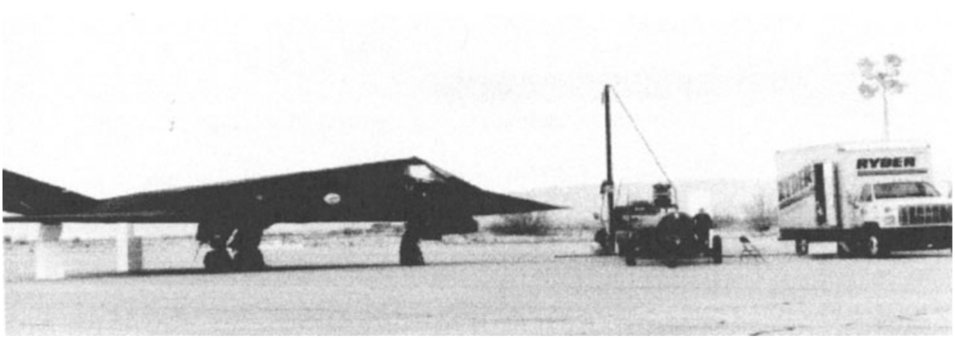

Figure 1: End view of the “3-D” RCS scanner and F-117.

Review of Progress in Quantitative Nondestructive Evaluation, Vol 16
Edited by D.O. Thompson and D E. Chimenti, Plenum Press, New York, 1997

The picture illustrates the mobility of the UWB holographic system for insitu UWB holographic imaging and RCS verification of LO signatures. Typical scan time for a small aircraft (forward looking view) would be approximately 4 hours at "X" band using the existing system. If the vertical scanner is replaced with a linear array, full aspect angle RCS could be generated in less than 30 minutes

The UWB Holographic Radar utilizes a low power radar transceiver (or an array of transceivers) that is physically or electronically scanned over a rectangular aperture near the vehicle (few meters). The low gain antenna/transceiver unit illuminates the vehicle with a wide beam-angle (spherical wave) at every scanned position in the aperture. The recorded data at each position is a vector sum of far-field plane waves at every frequency in the radar signal (UWB hologram).

The holographic data is rapidly processed by an on-site computer using a "Backward Wave" algorithm based on the Fast Fourier transform technique. The algorithm decomposes the spherical wave data into plane wave data and then back propagates them to the image plane (vehicle) forming the high resolution "3-D" radar image.

The on-line presentation on the computer display is as if the operator were using a optical "radar camera" to view the object. The vulnerable (hot spot regions) of the vehicle are precisely mapped in this presentation and then can be subdued with the application of radar absorbing material (RAM).

COMPUTER RECONSTRUCTION OF IMPULSE DATA

Assume the radar holographic system operates in a mono-static mode and the signal received at the scanned aperture is expressed by the following equation:

$$s(x', y', o, f) = \iint f_T(x, y, z, f) e^{j2kR} \, dxdy \tag{1}$$

where

$f_T(x, y, z, f)$ = target reflectivity
R = $\sqrt{(x'-x)^2 + (y'-y)^2 + z^2}$ = distance to the target
k = wave number
x,y,z = target coordinates
x',y',0 = receiver coordinates
f = frequency

$$e^{j2kR} = \text{spherical wave} = \iint e^{jk_{x'}(x'-x) + jk_{y'}(y'-y) + jk_{z'}(o-z)} \, dk_{x'} dk_{y'} \tag{2}$$

The spherical wave can be expressed as a vector summation of plane waves. If we substitute this expression into equation (1), the received signal is given by the following equation.

$$s(x,y,z,f) = \iint \{ \iint f_T(x,y,z,f) e^{-j(k_{x'}x + k_{y'}y)} dxdy \} e^{j(k_x'x + k_y'y)} e^{-jk_z'z} dk_{x'} dk_y \tag{3}$$

The term in brackets is the target's plane wave angular spectrum (i.e., Fourier Transform of target's reflectivity).
We can express it by the following equation.

$$A_T(k_x,k_y,z,f)=\iint f_T(x,y,z,f)e^{-j(k_{x'}x+k_{y'}y)}dxdy \tag{4}$$

We can then write eqt.(1) as

$$s(x',y',o,f)=\iint A_T(k_x,k_y,z)e^{j(k_{x'}x'+k_{y'}y')}e^{-jk_{z'}z}dk_{x'}dk_{y'}=$$
$$FT^{-1}[A_T(k_x,k_y,z)e^{-jk_{z'}z}] \tag{5}$$

The result of taking the Fourier Transform (both sides) of eqt.(5) is

$$FT[s(x',y',o,f)]=A_T(k_x,k_y,z)e^{-jk_{z'}z}=A_0(k_{x'},k_{y'},o) \tag{6}$$

This expression uniquely defines the target's angular spectrum in terms of the angular spectrum computed from the recorded aperture data ..s(x',y',0,f) and the back propagation factor $e^{jk_{z'}z}$.

$$A_T(k_x,k_y,z)=A_0(k_{x'},k_{y'},o)e^{jk_{x'}z} \tag{7}$$

UWB HOLOGRAPHIC IMAGE

The UWB image of the target is simply the absolute value of the inverse Fourier Transform of its angular spectrum (all frequencies).

$$\text{IMAGE}=f_T(x,y,z,f)=FT^{-1}[A_T(k_x,k_y,z)]=FT^{-1}[A_0(k_{x'},k_{y'},o)e^{jk_{z'}z}] \tag{8}$$

and can be written as

$$\text{IMAGE}=FT^{-1}[FT[s(x',y',o,f)]e^{jk_{z'}z}] \tag{9}$$

where

$$k_{z'}=\sqrt{4k^2-(k_{x'})^2-(k_{y'})^2} \tag{10}$$

If the military target is thick (end view), then the process is repeated for all depths and the image planes integrated with respect to the brightest pixels, etc., into one composite image.

EXPERIMENTAL RESULTS

Figure 2 is the UWB holographic image of a full-scale helicopter constructed with the large transportable scanner. This example shows the efficacy of the technique to produce an identifiable image of the aircraft and its "3-D" RCS maps in a single data scan. RCS data from a particular aircraft is directly coupled with its picture and is, therefore, easily identified. This is a unique feature of near-field UWB holography image data.

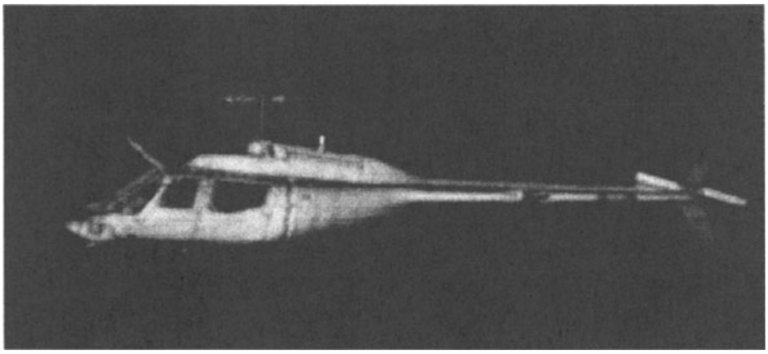

Figure 2: UWB holographic image of full-scale helicopter.

Figure 3 is a typical single frequency "3-D" RCS map of the helicopter at 10.5 Ghz. If 32 frequencies are digitized in the sweep (X band), 32 different maps can be generated with a single data scan. This would provide an abundance of all-aspect angle RCS data for LO signature analysis.

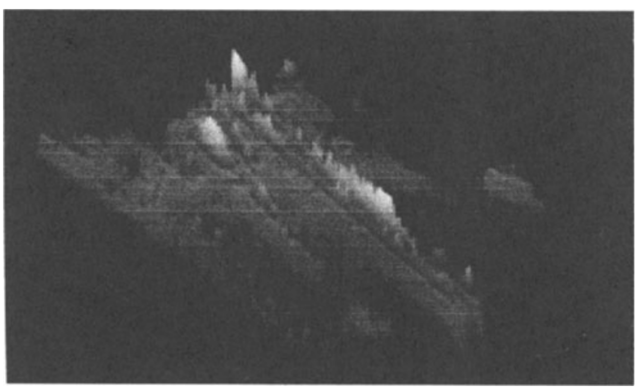

Figure 3. "3-D" RCS map at 10.5 Ghz of helicopter.

CONCLUSIONS

Previous research and development efforts with UWB holographic imaging and RCS have proved the viability of this technique for LO diagnostics with U S Army helicopters (Edwards AFB) and the F-117 at (Holloman AFB).

The advantages over conventional (SAR) imaging and RCS (farfield) techniques include the following:

1. Measurements can be performed in the nearfield (low cost)
2. Provides evaluation of stealth vehicles in hangers (security from satellites)
3. Provides quality control of stealth vehicles at production facilities (low cost)
4. Produces high resolution "3-D" images.